

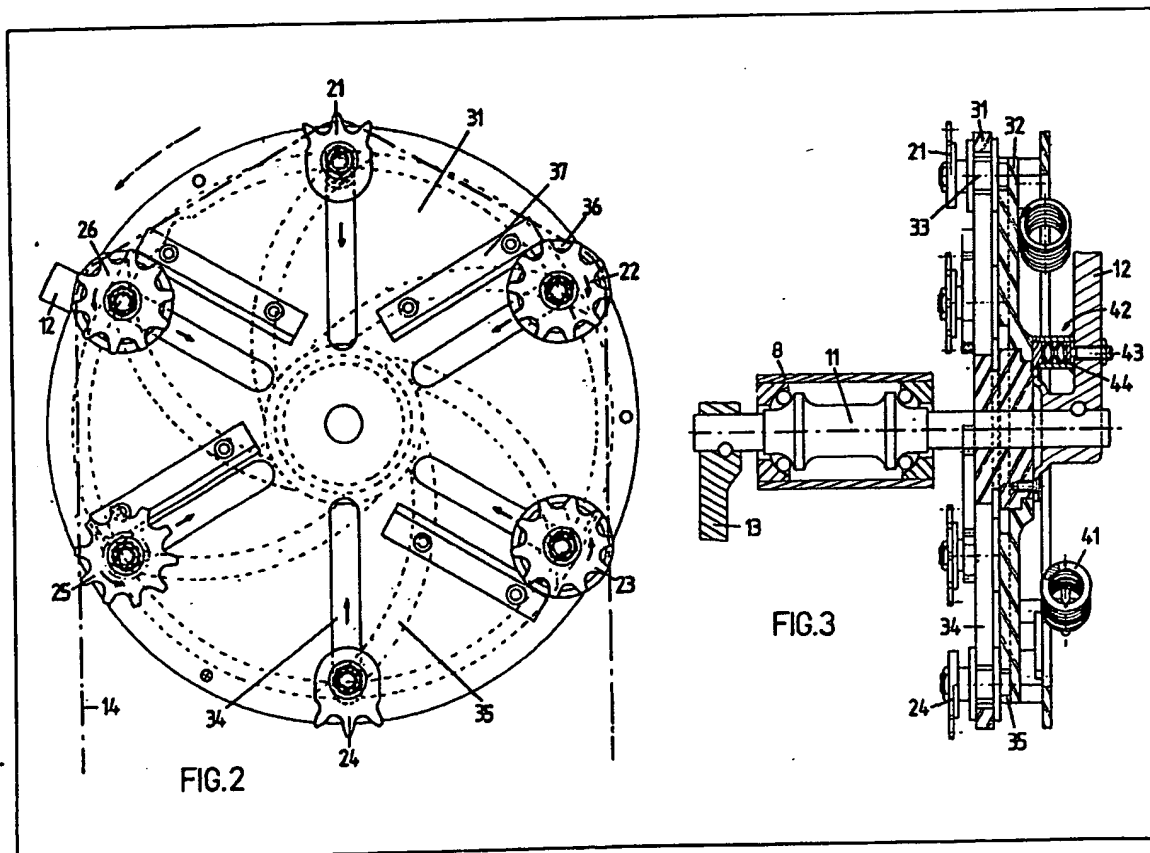
(21) Application No 8034485  
 (22) Date of filing 27 Oct 1980  
 (30) Priority data  
 (31) 7937436  
 8008245  
 (32) 29 Oct 1979  
 11 Mar 1980  
 (33) United Kingdom (GB)  
 (43) Application published  
 20 May 1981  
 (51) INT CL<sup>3</sup>  
 B62M 9/08 F16H 11/08  
 (52) Domestic classification  
 F2D 4B  
 (56) Documents cited  
 GB 1463406  
 GB 1320501  
 GB 625124  
 GB 563512  
 GB 463712  
 GB 228134  
 WO 80/02129A  
 WO 79/00522A  
 (58) Field of search  
 F2D

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(54) Variable diameter transmission  
 wheel

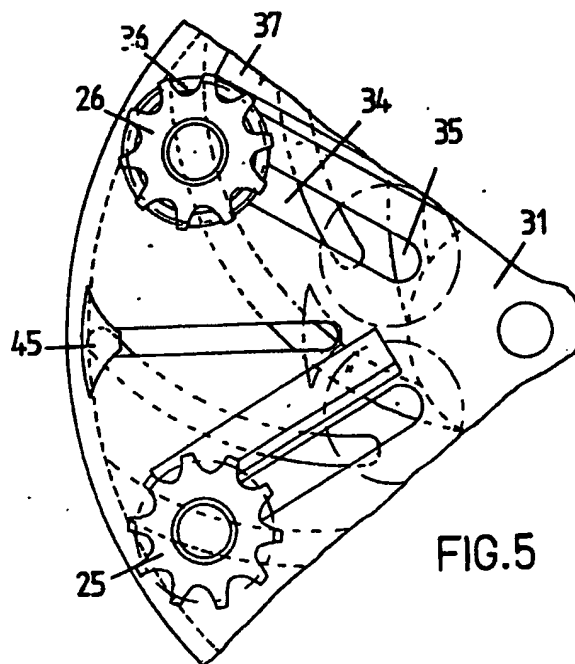
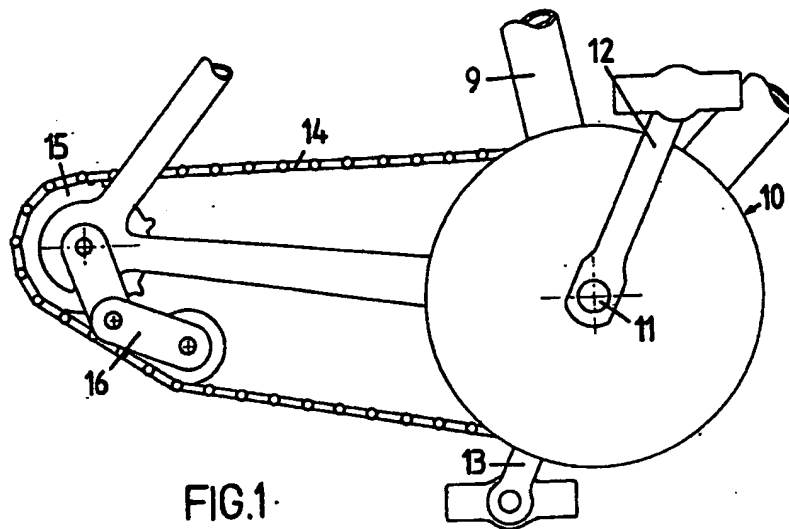
(57) An automatic variable speed  
 chain transmission includes a variable  
 diameter sprocket including a rotary  
 support (31) carrying six or more  
 radially movable toothed elements

(21, 22) etc., whose radial positions  
 are determined by engagement of  
 their spindles (33) with co-operating  
 spiral grooves (35) in another rotary  
 plate (32). At least some of the  
 toothed elements are rotated through  
 different angles, and some in different  
 directions, by rack and pinion means  
 (37, 36), to ensure proper alignment  
 with the teeth of the chain for all  
 different effective diameters of the  
 sprocket. A spring (41) acting  
 between the rotary discs (31, 32)  
 provides automatic adjustment of the  
 sprocket diameter and hence the gear  
 ratio. Instead of guiding the individual  
 toothed elements in radial slots they  
 may be mounted on tangential pivoted  
 links (52, 53).



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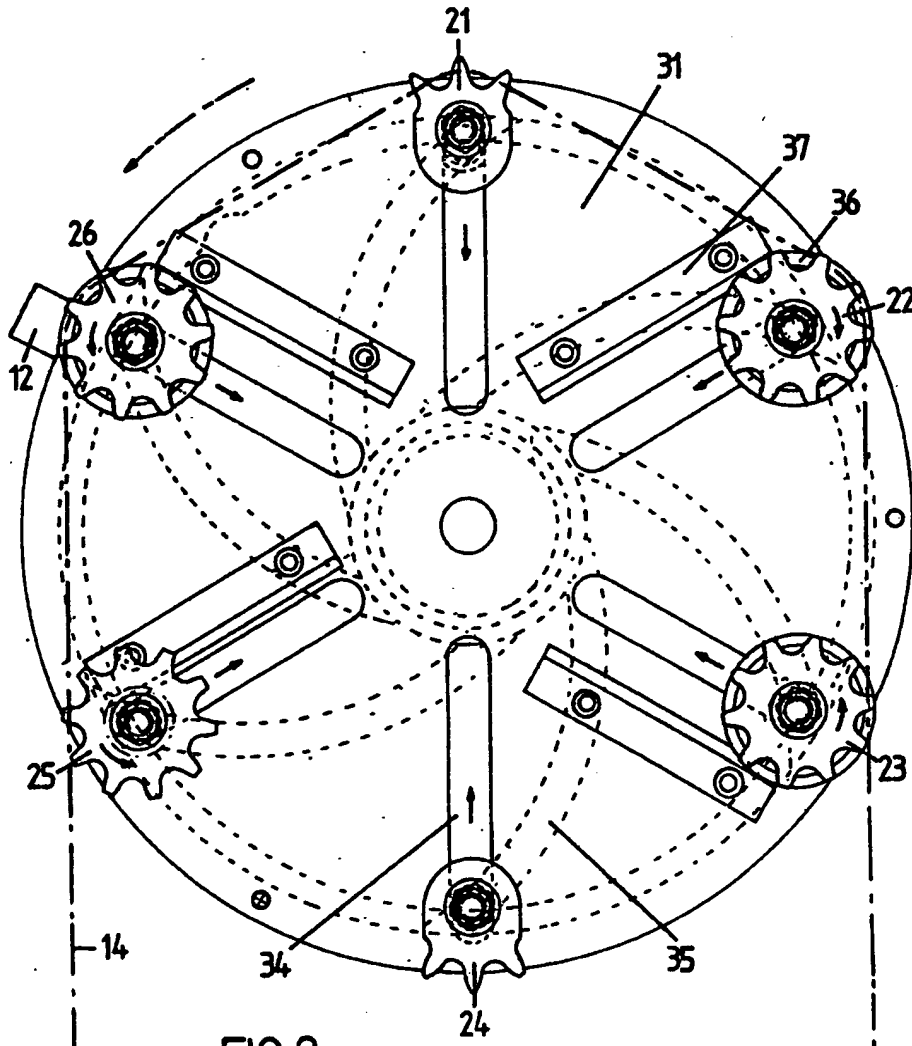
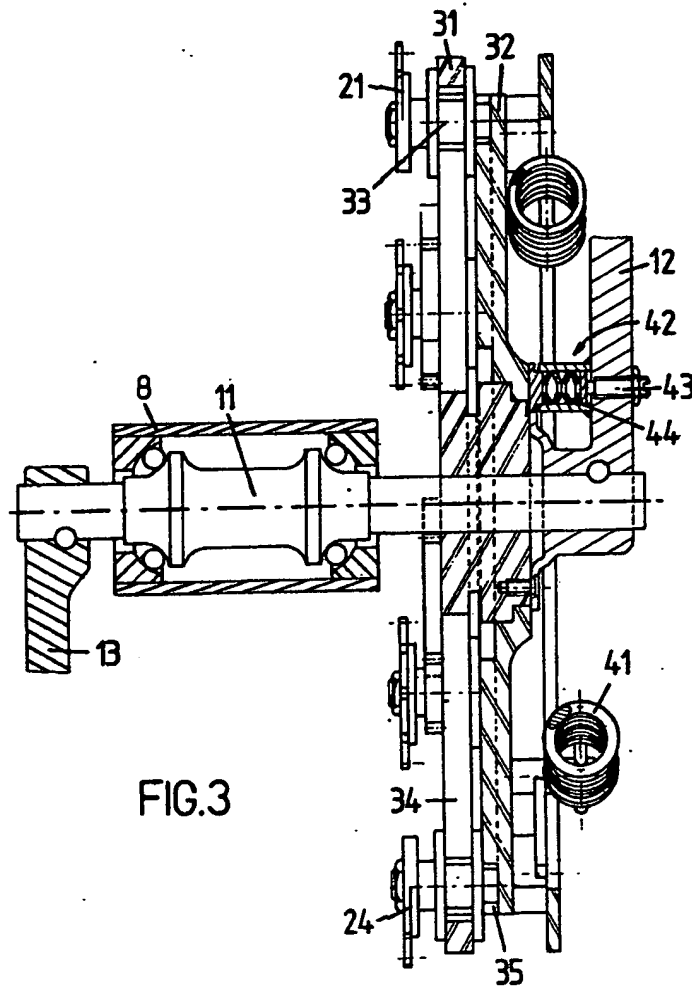


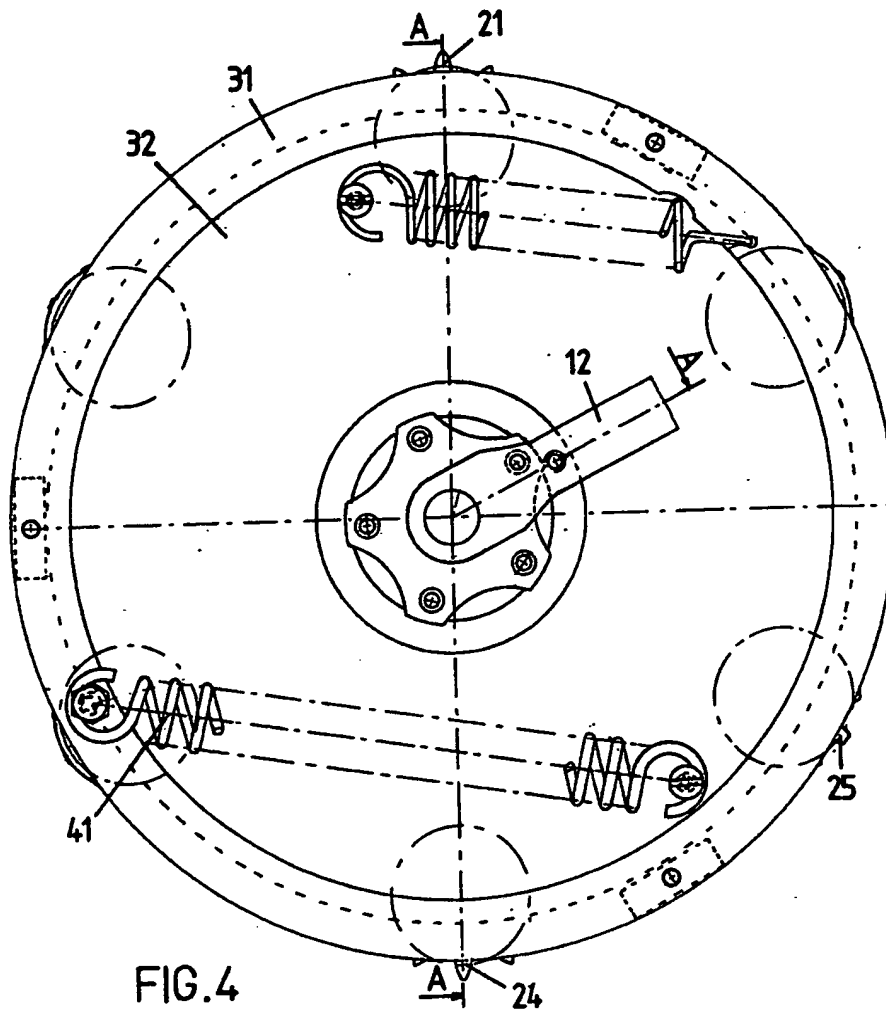
FIG. 2

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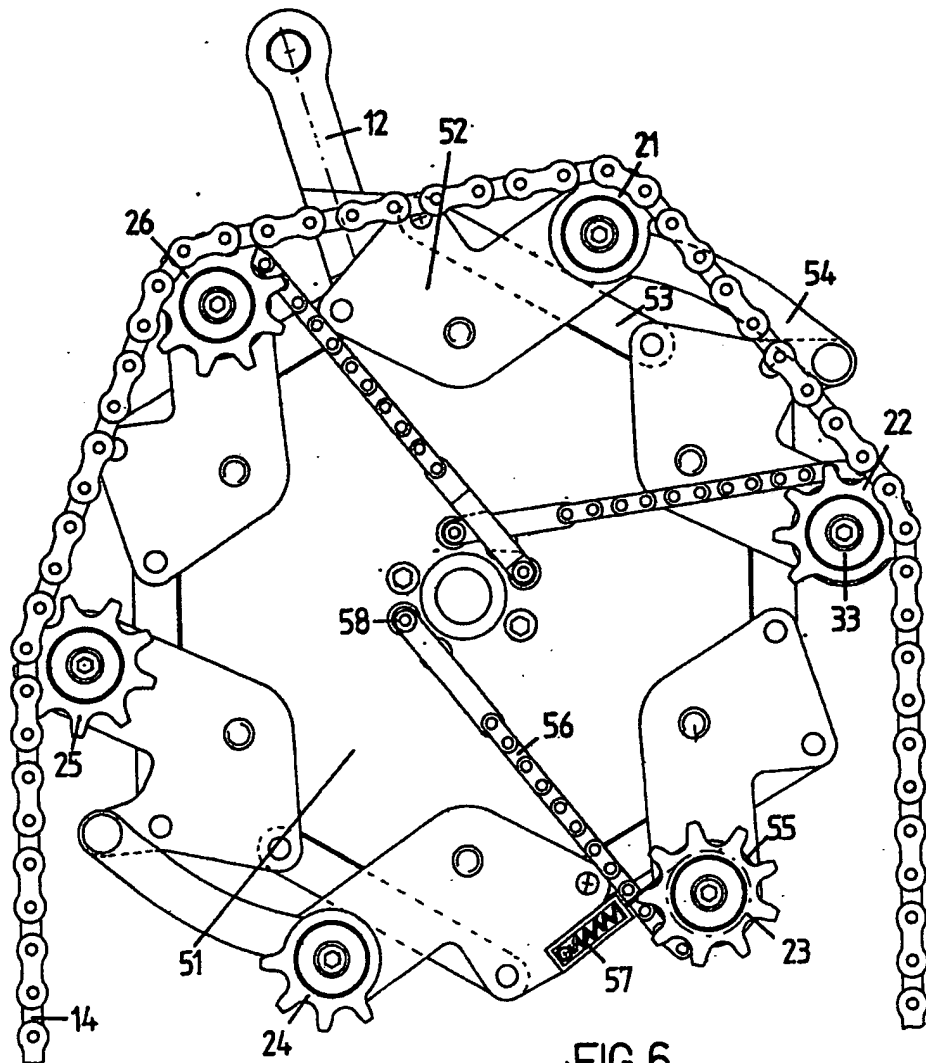


FIG. 6

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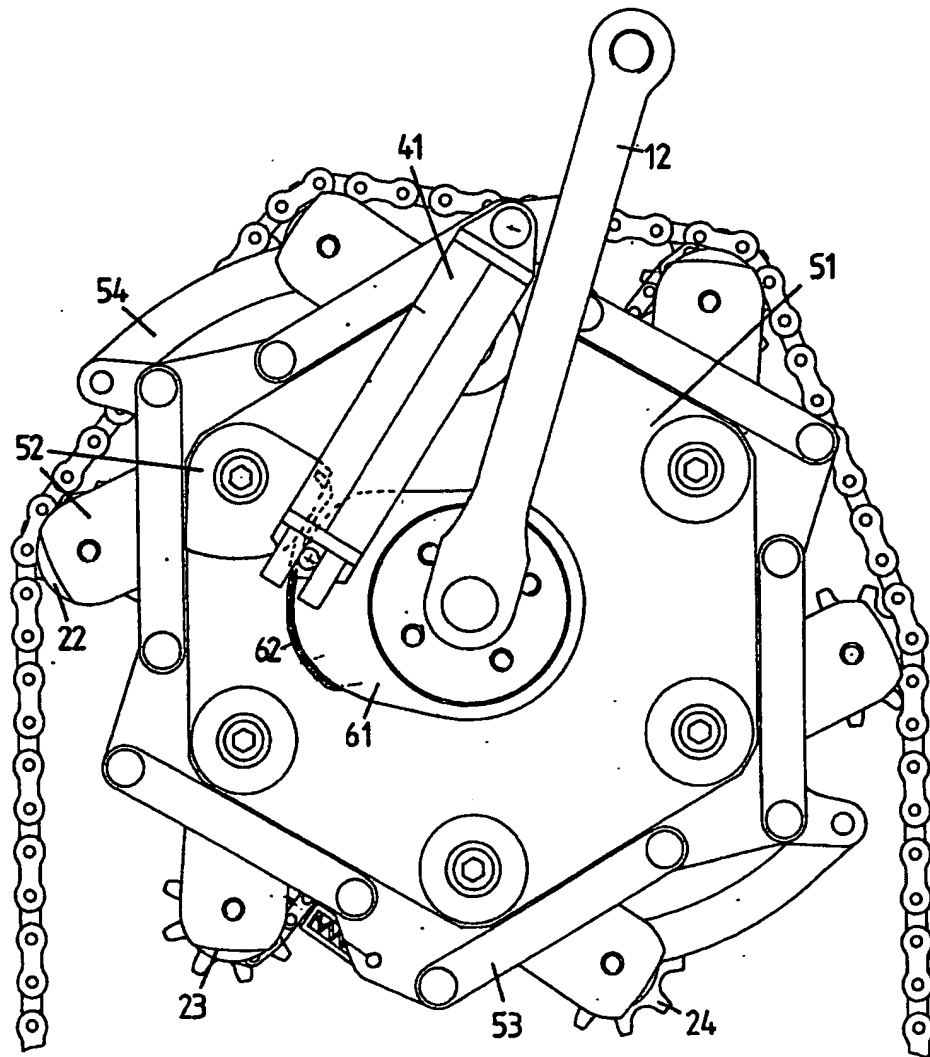


FIG. 7

## SPECIFICATION

## Variable diameter transmission wheel

This invention relates to a variable effective diameter wheel to be used in mechanical power transmissions in the form of either a pulley or a chain wheel. The invention is particularly though not exclusively applicable to belt or chain drives and some forms of the invention provide an infinitely variable ratio adjustment, or a continuously variable adjustment between pre-determined ratios. The transmission may or may not be fully automatic and self-contained. A particularly interesting application is a bicycle chain transmission with automatic speed ratio selection.

There have been numerous proposals to construct variable ratio transmissions, either of a stepping or infinitely variable type. All known systems suffer from limitations or disadvantages and it is an object of the present invention to provide an improved system, better suited to certain specific conditions.

For example in bicycle chain drives the well-known internal hub gear suffers from low efficiency, limited number of gear ratios, and inability to change ratios under load. The other well known alternative, the derailleur system, also has limited ratios, and suffers from chain misalignment and an inability to change ratios while stationary or under excessive load.

Broadly stated the invention consists in a rotary drive device for a rotary transmission including an endless flexible tension element, the device including a rotary support carrying a plurality of angularly spaced contact elements for the tension element, the contact elements being movable each in a generally radial direction, and including means controlling their radial displacement inwards and outwards to vary the effective diameter of the device.

According to a preferred feature of the invention the contact elements are movable radially inwards and outwards while the support is either static or rotating.

In one preferred form of the invention the support is provided with a series of generally radial guides for the contact elements, and the device includes a control element pivotally movable in relation to the support and having a corresponding series of inclined guides co-operating with the radial positions of the contact elements. Alternatively, each contact element may be mounted on a pivoted arm attached to the support, and there may be interconnecting links coupled between the guide arms to provide for radial movement of at least some of the contact elements in unison.

Conveniently each of the coupled arms is linked to adjacent arms via two separate connecting links each arranged to form a parallelogram linkage with the respective adjacent arm.

The invention is particularly applicable for use with a chain or toothed belt tension element, in which some of the contact elements are provided

with one or more teeth or notches to engage with the tension element. In such case some of the contact elements are rotary or pivotal toothed members, and the device will include means for controlling the pivotal movement of different contact elements through controlled conjugal angles. According to another preferred feature the conjugal angle control means is arranged to rotate different contact elements through different multiples of a variable angle, and special benefits can be obtained by including means for rotating different ones of the contact elements in different directions. In any case the device preferably includes means for preventing or restraining pivotal movement of at least two spaced contact elements.

Various methods may be adopted for controlling the pivotal movement of the contact elements. In one form there is a rack mounted generally radially on the support and an engaging pinion connected to the contact element, and in another form there is a flexible tension element or link connected at one end to the contact element and at its other end to a relatively stationary part on the support. One method of preventing pivotal movement of a contact element is to use a parallel motion linkage holding the attitude of the element fixed in relation to fixed points on the support.

According to another preferred feature of the invention the device includes blocking means preventing radial displacement of the contact elements over a controlled sector of the rotation of the support. In one form there may be an automatic cam lock operated by rotation of the support and effective over a predetermined sector of rotation of the support with respect to a fixed frame. Preferably, however, the blocking means is arranged to prevent radial displacement of the contact elements over a sector of the support which is fixed in relation to a driving crank or spindle. Blocking may be obtained by blocking relative pivotal or rotary movements between the contact elements and for this purpose the main chain may be used itself to prevent relative rotation. Blocking preferably extends over an arc of more than  $225^\circ$  and preferably in excess of  $240^\circ$ . Optimum results are obtained by blocking any adjustment of the ratio over at least  $300^\circ$ .

According to another particular preferred feature of the invention the device is automatically adjustable in response to changes on the load applied to the tension element. For example, it may include a resilient device acting between the support and at least some of the contact elements and acting radially outwards on the elements.

The invention is particularly applicable to vehicle transmissions, particularly bicycle chain drives, but may be used for other industrial power transmissions.

Two examples of the invention are illustrated by way of example in the accompanying drawings, in which:

Figure 1 is a side view of the lower part of a complete bicycle including the chain drive between pedals and rear wheel,



Figures 2, 3 and 4 are a left hand side view, a section through the axis of rotation along the plane A—A; and a right hand side view respectively, of the variable speed chain drive sprocket,

Figure 5 is a partial left hand side view of a chain wheel featuring non-toothed chain contact elements,

Figure 6 and 7 are a left hand side view and a right hand side view respectively of a second embodiment of the invention in the form of another variable diameter bicycle chain wheel.

Figure 1 illustrates the integration of the automatic transmission according to the invention in a bicycle whose frame is illustrated at 9: the automatic chain wheel 10 is mounted on the axle 11 supported by bearings within the bracket 8 like any conventional chain wheel and rotated by the pedal cranks 12 and 13 in the same manner. It drives the rear wheel (not illustrated) through a chain 14, constituting the endless flexible tension element), a sprocket 15 and a chain tensioning device 16. Except when an overriding device is fitted, the automatic transmission has no external controls, the gear changes being initiated and carried out solely by the action of the cyclist's legs on the pedals.

Referring to Figures 2 to 3, the variable effective diameter bicycle chain wheel comprises a rotary support in the form of a disc 31 carrying a relatively rotary control plate 32. The disc 31 supports six chain contact elements in the form of peripheral sprocket wheels or sectors 21, 22, 23, 24, 25 and 26, equally spaced, the spindles 33 of which can slide radially in slots 34 formed in the disc. Each spindle 33 engages at its back end with a spiral slot 35 formed in the control plate 32. The six spiral slots 35 of the control plate 32 are identical and equally spaced. While maintaining the peripheral sprockets in relative radial position, they convert any sprocket radial displacement into a control plate angular displacement and vice versa. The two sprocket sectors 21 and 24 are fixed rigidly on their spindles 33. Flats cut in these two spindles prevent any rotation of the sprocket sectors 21 and 24 relative to the disc 31. The four sprocket wheels 22, 23, 25 and 26 can rotate relative to the disc 31. Each sprocket wheel is controlled in rotation by a gear 36 mounted coaxially on its spindle 33. The gear 36 meshes with a rack 37 secured radially to the disc 31. The four sprocket wheels 22, 23, 25 and 26 have the same pitch circle diameter. The pitch circle diameter of the gears 36 associated with the sprocket wheels 22, 23 and 26 is equal to the sprocket pitch circle diameter, while that of the gear 36 associated with the sprocket 25 is equal to half its diameter. The racks 37 are located on the appropriate side of the respective slots 34 to ensure that in most cases when a sprocket wheel (22, 26, etc.) moves inwards it also rotates in a direction to shift the sprocket teeth away from the "fixed" sprocket sector 21, as illustrated by the arrows on the sprockets in Figure 2. This ensures that the distance between teeth on at least some

adjacent sprockets is at all times correctly related to the pitch of the chain 14. Sprocket wheel 23 is however a special case. The rack 37 of sprocket 23 lies on the side of the respective slot adjacent to sprocket 24. The chain 14 never engages with all the sprocket wheels and sectors at the same time. As shown in Figure 2, it engages with five of them, or sometimes only four. With the gear and rack arrangement described above, the chain wheel can expand or contract its effective diameter in a continuous manner only when the chain engages solely with the four sprockets 25, 26, 21 and 22 and no others.

Assuming that the upper and lower "runs" of the chain 14 are approximately parallel, as shown in Figure 2, it follows that expansion or contraction of the overall effective diameter is only possible within a limited sector, not exceeding 60°, of the rotation of the support disc 31. Over the remaining sector of at least 300°, the expansion and contraction is completely blocked. This results from the fact that throughout this blocked sector the chain 14 will be in engagement with sprocket 23 or 24, or both, and in this condition at least one pair of sprockets, by the geometrical arrangement, will tend to rotate in opposite directions, against the resistance of the non-extensible chain 14. This totally blocks expansion of the contact elements but of course still permits contraction, since the chain can then go slack. In addition the gear and rack arrangement combined with the slots 34 and 35 provides the reaction forces which control the transmission speed ratio through two springs 41 which couple the control plate 32 to the supporting disc 31, and a friction device 42 which is placed in parallel with the springs 41. This friction device 42 consists of a screw 43 mounted in the crank 12 and compressing a spring 44, thereby pinching two parts of the disc 31 against opposite sides of the control plate 32. In the unblocked 60° sector of the chain wheel rotation where the effective diameter is continuously variable, the gear and rack arrangement creates reaction forces which, via the spindles 33 and the radial and spiral slots 34, 35 balance the resisting torque provided by the two springs 41 and the friction device 42. In the unblocked sector the sprockets 25, 26, 21 and 22 engage with the chain and transmit the load through the sprocket 22 which is the last or outside element in contact with the chain. The rack 37 and gear 36 create a reaction force on sprocket 22 directed inwards, which is opposed by spring 41 and friction device 42. In the blocked chain wheel angular positions where the wheel cannot expand, the gear and rack arrangement generally provide reaction forces directed outwards which tend to expand the chain wheel against the non-extensible chain, thereby effectively blocking any variation in diameter. This is the case of example when the load is transmitted to the chain by the sprocket 23, which due to its associated rack tends to move radially outwards. The crank 12 is fixed to the supporting disc 31.

The angular positions of the cranks 12, 13, in relation to the disc 31 is very important. The design factors are complex but in general one crank should be within a range where the leg-force is nearly maximum and hereby constant, while the disc 31 is in its unblocked sector. As a rough approximation the disc should be unblocked over a range which at least partly overlaps with the crank moving downwards within 60° below the horizontal.

In operation, the chain wheel effective diameter remains maximum as long as the leg-imparted torque  $T_1$  is less than a preset threshold value  $T_p$ . This value  $T_p$  is a function of the sum of the prestressing spring torque  $T_s$  and the total friction torque  $T_f$ . If  $T_1$  increases so that it exceeds the threshold value  $T_p$ , it will cause the chain wheel to shrink when it passes through the unblocked sector of 60° of continuous variation. Unless the chain wheel diameter becomes minimum, the chain wheel contraction will stop at the diameter where the torque transmitted to the control plate 32 by the spindles 33 balances the resisting torque. For many possible radial positions this diameter will not correspond exactly to a chain wheel with a whole number of effective teeth. As the chain enters in a contact with sprocket 23, the torque exerted by the spindles 33 falls sharply and the chain wheel expands to the first diameter which corresponds to a whole number of effective teeth. Since the value of the coefficient of static friction is substantially greater than that of dynamic friction, the chain wheel possible cyclic fluctuations between two wheels with a whole number of effective teeth are normally prevented. Chain wheel expansion takes place in the same sector of 60°, when the leg imparted torque  $T_1$  falls below the value where the torque exerted by the control plate onto the spindles 33 become greater than the spindle resisting torque. Depending on the amount of friction inherent in the system, the chain wheel will exhibit more or less torque "hysteresis" between contraction and expansion thus eliminating undesirable high speed cyclic variations. Alternatively the spindles 33 may be "biased" or encouraged to adopt and hold the selected diameter positions, by providing spring detents at selected radial positions along the length of each radial slot.

A particularity of this chain wheel is that its effective contour is a rounded polygonal. Whilst the degree of chain wheel "roundness" provided by six peripheral sprockets meets bicycle requirements, for industrial and automotive applications, it may be essential to make the chain wheel rounder. This can be achieved by increasing the number of sprockets. Alternatively, in order to maintain a high speed ratio range, the basic sprockets can be complemented with non-toothed chain supporting elements 45 (Figure 5) placed at equal intervals between the sprockets and movable in the same way. These elements can be regarded as sprockets, the function of which is only to support the chain.

Referring to Figures 6 and 7, the variable

effective diameter bicycle chain wheel comprises a disc 51 on which pivot six arms 52. The arms 52 are kept in relative position by six interconnecting links 53, arranged to form parallelogram linkages with their neighbours. The arms 52 carry the spindles 33 of the six peripheral sprockets 21, 22, 23, 24, 25 and 26. All six sprockets can rotate about their spindles, but the sprocket sectors 21 and 24 are held in fixed attitudes relative to the disc 51 by additional parallelogram links 54. The sprocket 25 rotates freely. To control the rotation of the sprockets 22, 23 and 26, pulleys 55 and anchor chains 56, wrapped around the pulleys and anchored at 58, are used as an alternative to gears and racks. Their arrangement is very similar to that used in the first embodiment. The chain 14 contributes to the rotation of the sprockets 22, 25 and 26 conjugate to their radial displacement, the chain 14 engaging with them when the chain wheel expands or contracts in a continuous manner. In order to rotate the sprocket 23 when the chain wheel is contracted, a spring 57 is used to keep the anchor chain 56 under tension. The crank 12 is secured to the disc 51. To oppose the sprocket reaction forces which tend to move them radially inwards, a compression spring 41 is placed between the crank 12 which is fixed to the disc 51 and the swinging arm 52 of the sprocket 22 via a cam plate 61 which rotates about the axis of rotation of the disc 51 and a cable 62 which pulls the arm 52 so as to expand the chain wheel.

In general it is desirable in all embodiments that the resultant of the spring forces should act radially outwards on at least one of the contact elements, (particularly the critical controlling element 22 in Figure 2 or Figure 6). It is theoretically possible and feasible to locate a spring acting directly radially outwards on the spindle 33 of the sprocket 22.

## 105 CLAIMS

1. A rotary drive device for a rotary transmission including an endless flexible tension element, the device including a rotary support carrying a plurality of angularly spaced contact elements for the tension element, the contact elements being movable each in a generally radial direction, and including means controlling their radial displacement inwards and outwards to vary the effective diameter of the device.

2. A device according to Claim 1, in which the support is provided with a series of generally radial guides for the contact elements.

3. A device according to Claim 2, including a control element pivotally movable in relation to the support and having a corresponding series of inclined guides co-operating with the radial positions of the contact elements.

4. A device according to Claim 1, in which the contact elements are each mounted on a pivoted arm attached to the support.

5. A device according to Claim 4, including interconnecting links coupled between the guide arms to provide for radial movement of at least some of the contact elements in unison.

6. A device according to Claim 5, in which each of the coupled arms is linked to adjacent arms via two separate connecting links each arranged to form a parallelogram linkage with the respective adjacent arm.
7. A device according to any of the preceding claims, for use with a chain or toothed belt tension element, in which each of the contact elements is provided with one or more teeth or notches to engage with the tension element.
8. A device according to Claim 7, in which some of the contact elements are rotary or pivotal toothed members.
9. A device according to Claim 8, including means for controlling the pivotal movement of different contact elements through controlled conjugal angles.
10. A device according to Claim 9, in which the conjugal angle control means is arranged to rotate different contact elements through different multiples of a variable angle.
11. A device according to either of Claims 9 and 10, including means for rotating different ones of the contact elements in different directions.
12. A device according to any of the preceding claims, in which some of the contact elements are rotary, and including means for preventing or restraining pivotal movement of at least two spaced contact elements.
13. A device according to any of Claims 9 to 12, in which the means controlling the conjugal displacement angle of selected contact elements, comprises a rack mounted generally radially on the support and an engaging pinion connected to the contact element.
14. A device according to any of Claims 9 to 12, in which the means controlling the conjugal displacement angle of selected contact elements includes a flexible tension element or link connected at one end to the contact element and at its other end to a relatively stationary part on the support.
15. A device according to any of preceding Claims, in which some of the contact elements are rotary, and including means for preventing pivotal movement of at least one contact element, comprising a parallel motion linkage holding the attitude of the element fixed in relation to fixed points on the support.
16. A device according to any of the preceding claims, including blocking means preventing radial displacement of the contact elements over a controlled sector of the rotation of the support.
17. A device according to Claim 16, in which the blocking means includes an automatic cam lock operated by rotation of the support and effective over a predetermined sector of rotation of the support with respect to a fixed frame.
18. A device according to Claim 16, in which the blocking means is arranged to prevent radial displacement of the contact elements over a sector of the support which is fixed in relation to a driving crank or spindle.
19. A device according to any of Claims 16 to 18, in which blocking of the radial movement of the contact elements is obtained by blocking relative pivotal or rotary movements between the contact elements.
20. A device according to Claim 19, in which blocking of the radial displacement is obtained by means of the main chain or toothed tension element, engaging the toothed contact elements.
21. A device according to any of Claims 16 to 20, in which radial movement of the contact elements is blocked over a sector which exceeds  $225^\circ$  and preferably exceeds  $240^\circ$ .
22. A device according to any of Claims 1 to 21, in which radial movement of the contact elements is blocked over a sector of at least  $300^\circ$ .
- claims, in which the means controlling the radial positions of the contact elements is adjustable or controllable externally, by a manual or powered control, arranged to be operable in either direction during rotation of the support.
24. A device according to any of the preceding Claims 1 to 22, in which the means controlling the radial positions of the contact elements is automatically adjustable in response to changes on the load applied to the tension element.
25. A device according to Claim 24, in which the automatic control includes a resilient device acting between the support and at least one of the contact elements and acting radially outwards on the element.
26. A device according to any of the preceding claims in which the tension element and the contact element are toothed, and including means for adjusting the relative conjugate angles of the contact elements to correspond with the tooth spacing of the tension element, and in which the elements are movable into any one of a series of radial positions representing different whole tooth member pitch circle diameters, and are continuously variable between such whole pitch positions during rotation of the support.
27. A device according to any of Claims 7 to 26, including additional non-toothed contact elements interposed angularly between the toothed contact elements.
28. A device according to any of the preceding claims, in which the contact elements are movable radially inwards and outwards while the support is either static or rotating.
29. A device according to any of the preceding claims, forming part of a rotary transmission between a prime mover such as a motor and a rotary output element.
30. A device according to any of Claims 1 to 28, forming part of a variable speed transmission for a bicycle or other vehicle.